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Developing Pavement Performance Functions for Palestinian Roadway Network

تطوير علاقات الأداء للرصفات الإسفلتية في المناطق الفلسطينية

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Abstract

The measurement and prediction of pavement performance condition is an essential component of any pavement management system. In this paper, performance evaluation method for Palestinian roadways was developed. Estimation of the flexible pavement performance life for maintenance and rehabilitation was presented. Data for model development was collected based on the pavement evaluation methods issued by the World Bank for developing countries. The performance model developed in this paper was based on evaluation of various deterministic and probabilistic models using surveyed data for arterials and village access roads in Palestine. The pavement performance models were developed based on calibration of surveyed pavement condition rating index using logistic growth model, and applying regression analysis. The results of the analysis showed that the logistic growth model performed well in fitting the calibrated data for the different roadways considered in this study and the Markov model fitted well for the overlaid arterials. The reconstructed arterial roadway system had longer average performance life than the overlaid arterials. Village access roadway system showed the same behavior.

Keywords: Pavement, performance, function, pavement management system, probabilistic methods, Palestine.

ملخص

تعتبر شبكة الطرق في أية دولة في العالم من ضروريات التطور الاقتصادي، وللحفاظ على أداء جيد لهذه الطرق فقد تم وضع نظام لإدارة رصفات الطرق (Pavement System Management) منذ منتصف القرن الماضي، وأهم بنود النظام هو كيفية وصف حالة رصفات الطرق وتحديد أدائها (Pavement Performance) وكذلك التنبوء بأدائها بمرور الزمن. فتحديد هذا الأداء ضروري لمن هم في موقع القرار، ولمصمم الطرق وللهيئات المسئولة عن صيانة هذه الطرق. إن التطبيق الناجح والفعال لنظام إدارة رصفات الطرق يتطلب تحديد هذا الأداء لمعرفة المدة الزمنية لخدمة الرصفة، وهي بحالة جيدة قبل أن تحتاج إلى صيانة أو إعادة إنشاء. وبناءً على ما تقدم، فقد تم عمل دراسة مفصلة لتحديد أداء الرصفات الإسفلتية لشبكة الطرق في المناطق الفلسطينية. وتم تطبيق هذا البحث من خلال المعلومات التي تم جمعها عن حالة الطرق التي أجريت لها أعمال صيانة رئيسية منذ العام ١٩٩٥ وذلك بأخذ عينة ممثلة للطرق الرئيسية في مدينة نابلس وللطرق الرابطة القروية في المحافظة. والمعلومات التي تم جمعها لتطوير النموذج الرياضي تعتمد بصورة أساسية على طرق التقييم المعتمدة من قبل البنك الدولي للدول النامية. وتضمن هذا البحث دراسة عدة نماذج رياضية لتطبيقها على البيانات التي تم جمعها، وقد استخدم في هذه النماذج أنماط رياضية منها Deterministic ومنها أيضاً Probabilistic وذلك اعتماداً على البيانات التي تم جمعها من الطرق الشريانية أو الطرق الموصلة للمناطق الريفية في فلسطين. وشملت هذه النماذج Deterministic Regression Polynomial من الدرجة الثانية وDeterministic Logistic Growth و Probabilistic Markov لتحديد أداء الرصفات الإسفلتية. لقد تمت معايرة هذه النماذج الرياضية من خلال البيانات الميدانية التي تم جمعها أيضاً. وتبينَ من نتائج هذا البحث أن تطبيق نموذج Logistic Growth هو الأفضل من حيث مطابقته للبيانات الخاصة بحالة الطرق لتحديد أدائها و تطبيق نموذج Markov هو الأفضل من حيث مطابقته للبيانات الخاصة بالطرق الشريانية التي تم رصفها. وكما بينت الدراسة أن الطرق الشريانية التي تمت إعادة بنائها تعطي أداءً أفضل من خلال فترة خدمة أطول مقارنة مع مثيلاتها التي تم تأهيلها من خلال إعادة الرصف، وينطبق الاستنتاج نفسه على الطرق الموصلة للمناطق الريفية.

Introduction

The foundation and alignment of some existing roads in Palestine were established during the British mandate of Palestine. A considerable portion of those roads was constructed as Macadam roads following old foot paths with relatively tortured alignment due to the prevailing mountainous terrain and limited resources. During the thirty years of occupation of the West Bank and Gaza Strip, most of the roads have been deteriorated, while some of the urban streets have received some kind of

unorganized maintenance activities. In addition, during this era, focus was only on the construction and rehabilitation of settlement's main and access roads.

Since 1995, Palestinian National Authority has been playing a crucial role in the multi-disciplinary fields of planning, construction, rehabilitation, and maintenance of roadway infrastructure. Since then, various roads have been rehabilitated and constructed by the Palestinian Economic Council for Development and Reconstruction (PECDAR), related governmental agencies, and municipalities; while others are under rehabilitation and many under design and study. Maintenance and rehabilitation policy includes several roads such as arterials, local, collector urban roads, interurban roads, and many village access roads distributed all over Palestinian Governorates. Donor countries and the World Bank finance most of those road projects. Budgets allocated for this purpose were relatively high considering the amounts spent in the period of the Israeli occupation and length of roadway network in the West Bank and Gaza (PECDAR 2005). To meet the increasing demand for new roadway pavements, carry out the maintenance on the existing ones, and adapt a new pavement investment policy, there is a crucial need to establish a pavement management system for Palestinian roadway network.

Objectives

This research work is intended to establish pavement performance models through the assessment of current conditions of roadway pavements to predict future pavement conditions. Since roadway performance is an essential input to any decision making process concerning pavement rehabilitation policy of related governmental agencies, road conditions survey was performed on several arterials and village access roads for Nablus Governorate.

Background

Pavement management subsystems may range from relatively simple to very complex systems. The procedure utilized to provide estimates of

past and future truck loading on highway pavements could be regarded as being pavement management subsystem. A more complex subsystem is the one that provides feedback on pavement cost and performance information. Such information is then used for establishing priorities for construction or maintenance work; evaluating alternatives and selecting strategies for design, programming, construction, and maintenance of pavements; and assessing future pavement related needs. It is important to measure or evaluate this level of service to establish the current status of a pavement, and to predict the change of this level in the future (Botelho et al. 2000).

Cary and Irick provided in 1960 the most widely known means for the use of the objective roughness measurement for estimating the subjective pavement serviceability in developing the Present Serviceability Index (PSI) equation at the AASHTO road test (Hass et al. 1980).

In 1999, Hand et al, developed performance models based on Departments of Transportation (DOT's) Pavement Management Systems (PMS) data. The aim of this study was to develop for Nevada Department of Transportation (NDOT) a network optimization system (NOS). The objective of the system was to evaluate various alternatives and recommend the most effective rehabilitation treatment to be used on the various sections of the state highway system. The NOS consisted of several subsystems, which included performance models, life cycle cost analysis, and network optimization. NDOT had developed the performance models, selected the unit cost to be used in the life cycle analysis, and identified unique segments on the entire roadway network. In addition, the research discussed the pavement rehabilitation and maintenance costs. In order to perform Life Cycle Cost Analysis (LCCA) for comparison of alternatives and network optimization purposes, several cost factors must be determined. Cost factors are the costs associated with the LCCA for a facility or in comparing alternative designs that cover the full life cycle from initial design through the end of selected analysis period. First costs include both the initial construction cost, which are related to the design and construction of a rehabilitation

treatment. The cost of annual maintenance after the application of a rehabilitation or maintenance treatment may significantly affect the life cycle cost of that treatment.

Ping et al. (1999) analyzed flexible pavement performance for maintenance and rehabilitation applications. It was a research effort to estimate the average flexible pavement performance life in Florida for maintenance and rehabilitation applications. The pavement condition survey history data since 1976 from the Florida Department of Transportation (FDOT) was used for this analysis. Their work presented the development of a performance modeling procedure based on the polynomial model and results of analyzing past flexible pavement performance in Florida. The average pavement performance life cycles were evaluated for flexible pavement at the network level based on the performance curves.

Silva et al. (2000) proposed pavement performance models for local government agencies in Michigan. Various deterministic and probabilistic models were evaluated using data from two Michigan counties. It was found that the logistic growth model and Markov model provided the best combination of predictive ability and potential for applicability in Michigan counties. Counties currently use an objective, repeatable rating system for assessing pavement condition called Pavement Surface Evaluation and Rating (PASER), which is based on the visual condition of the pavement. The simplicity of this procedure makes data collection easier but also less accurate. Nevertheless, the system has been widespread in Wisconsin and Michigan for a number of years, and the accuracy of the data has been found to be adequate for local agency application.

Many deterministic model forms are available pavement performance predictions, including straight line extrapolation, S-shaped curves, polynomial constrained best squares, and logistic growth models. Kuo (1995) was the first to apply the logistic growth model to Michigan's pavements. Kuo's pavement model was based on an ascending distress index with different design service life values. In this formulation, the starting distress index of a reconstructed or resurfaced pavement was

established as zero. The model thus passed through zero at new construction.

The logistic growth model assumes that the growth rate at time "t" is proportional to the product of the population size at time "t" and the future amount of growth. As time "t" increases, deterioration approaches one hundred. Regardless of the values of these parameters, the curve has an S-shape and is symmetric about its point of inflection. However, the values of these parameters collectively determine the exact shape of the curve.

As an alternative to deterministic models, probabilistic models are sometimes considered. The Markov transition process is one probabilistic approach that has received attention by pavement engineers and researchers (Butt 1991). The principles of applying probabilistic models for the prediction of pavement deterioration were first discussed in the early 1970's. Since that time a considerable progress has been made in the development of the probabilistic models and their application to PMS. Still the major challenge facing the use of existing probabilistic models is difficulties with establishing the Transition Probability Matrix (TPMs) (Howard 1971).

Methodology

Road and street network represents a major area of investment in Palestine. The pavement portion of this investment is quite substantial. People who are interested in expanding funds allocated for these investments require an efficient set of management practices.

This paper aims at establishing a pavement performance model through the assessment of current conditions of roadway pavements and to predict the future pavement condition. Since roadway performance is an essential input to any decision making process concerning pavement rehabilitation policy of concerned governmental agencies, a road condition survey is performed on several arterials and village access roads in Palestine (PECDAR 2001) in accordance with the World Bank Manual for Developing Countries (WB & RTRP 1990) (Donnelly 1987).

This is considered as a feed back for establishing an integral database of roadway condition and related pavement characteristics.

An assessment of roadway condition is followed by developing pavement performance trends for flexible pavements that fit the observed roadway condition data. Prediction of roadway performance trends is determined through the use of polynomial regression analysis applied to the calibrated road condition data using logistics growth concept for modeling pavement performance. Through this process, a pavement performance life cycle was developed and analyzed for a representative arterial and village access roads. Based upon that, an evaluation was performed for roadway rehabilitation policy being adopted and pavement life cycle related to the developed performance model.

Data of pavement structure was grouped and categorized based on roadway classification, layers received rehabilitation or construction, and date of construction. Initial data verification and identification were done using Pavement Condition Rating (PCR) and MathCAD for Markov probabilistic model. Data is calibrated using the deterministic logistic growth model. Pavement life cycle is analyzed and compared with the models developed and the outcomes are used to support the decision making towards suitable maintenance and rehabilitation strategies.

Database

The sampling method selected to accommodate the objective of this study in modeling performance trend for roadway network using the cluster random method, by which a sample of the roadway network confined in a certain jurisdiction is selected to represent the network, since the roadway network is very large and distributed in different areas. Nablus Governorate is chosen to be the study area. Two road classifications are selected, which are arterial road and village access roads. Road network lengths in the West Bank and Gaza Strip by class are shown in Table 1.

Table (1): Road Network Lengths in the West Bank and Gaza Strip by Class (Kilometers).

Region	Main	Regional	Local	Total
West Bank	489	634	1125	2248
Gaza Strip	128	218	275	621
Total	**617**	**852**	**1400**	**2869**

Source: Palestinian Ministry of Transport, 2003

In this research, representative samples of arterials and village access roads were chosen for this study in the city of Nablus and it's Governorate (Figure 1). In selecting the road sampling, consideration was given to the years in service since the last maintenance or rehabilitation action the pavement has received. The total length of resurfaced arterials considered in this research based on cluster random method is 15.7 km and that of village access is 25.8 km. Figures 2 & 3 show the surveyed arterial and village access roads, respectively.



Figure (1): City of Nablus-Palestine.

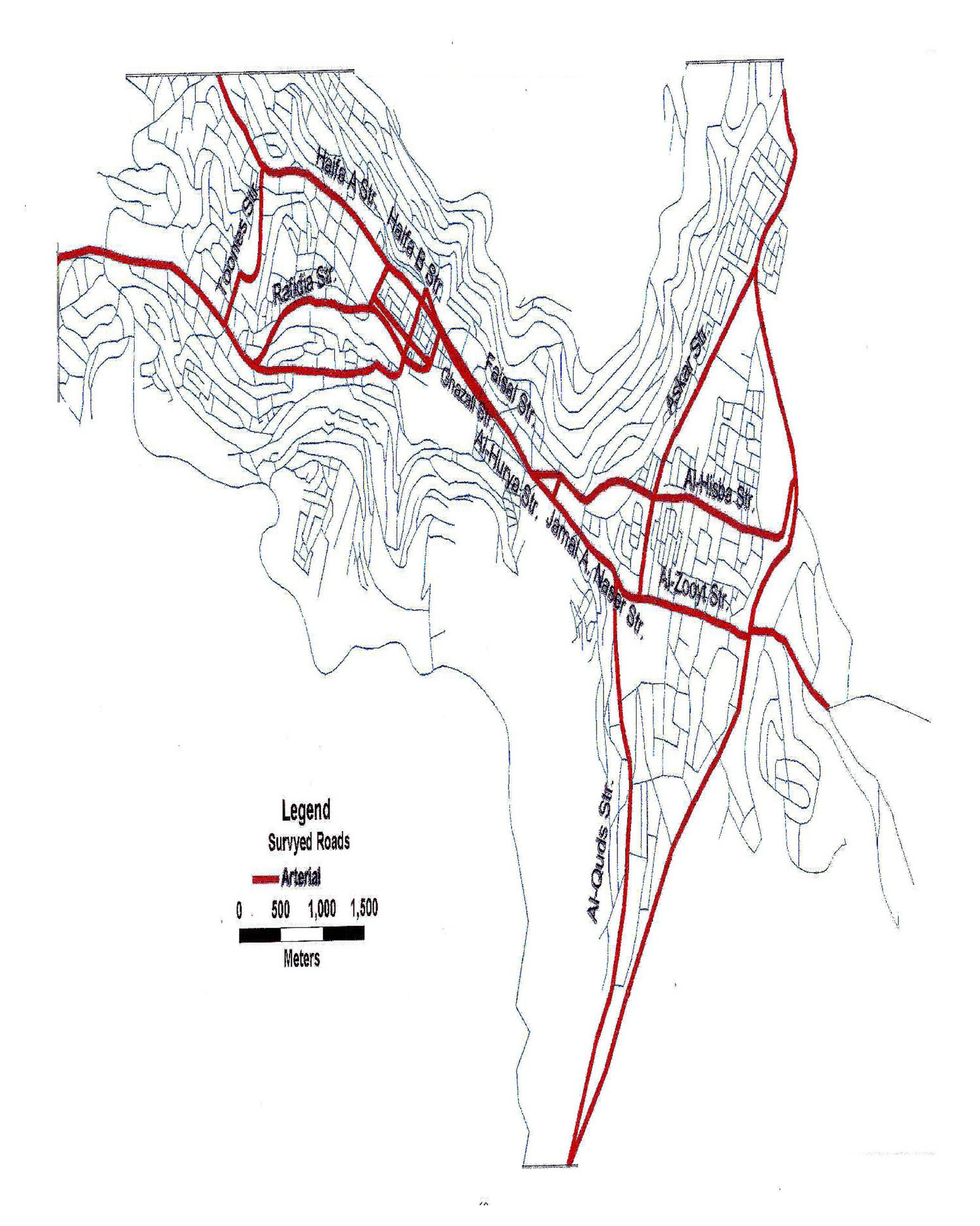


Figure (2): Surveyed Arterial Roads in the City of Nablus.

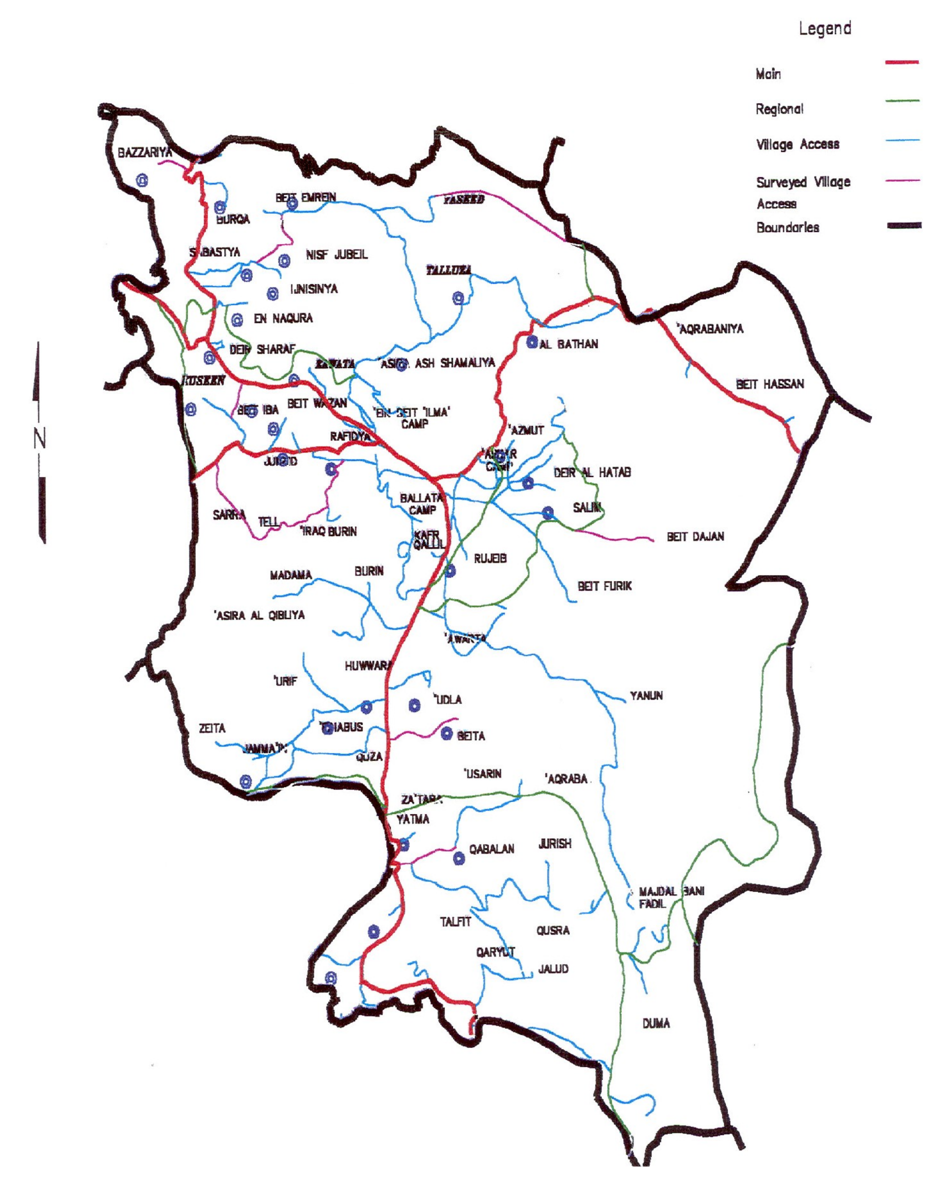


Figure (3): Surveyed Village Access Roads within the Nablus Governorate.

The database was categorized by roadway classification, sections, subsections, uniformity of cross section, and thickness of pavement structure. The length of arterial road sections was taken to be 100 m while that of the village access roads was 200 m based on the recommended ranged of section length by the OECD (1990). Figure 4 shows a typical division of an arterial into sections (each direction is considered as a section) and subsections (each direction is divided into subsections).

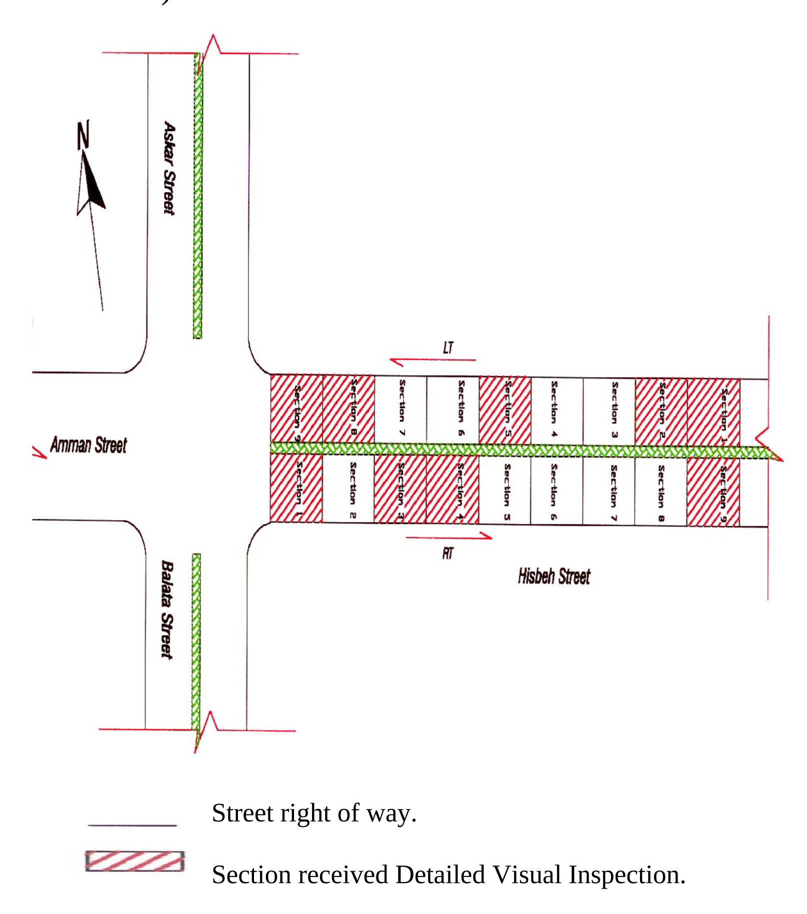


Figure (4): Typical Division of an Arterial into Sections and Subsections.

Percentage rating of the Road Condition Survey (RCS) for all the surveyed sections showed that 33.4 percent of the sections were in excellent condition while 45.3 percent were in good condition. The rest of the sections were approximately in a fair condition with only 6.9 percent in a poor condition.

Figure 5 represents the distribution of the RCS rating for overlaid arterial roads; arterial roads received major maintenance and village access roads. For the overlaid arterials, forty two sections were in excellent condition with a predominant rating of seventy four sections in good condition while the rest have lower rating. For the arterial with major maintenance, the RCS rating for sixty-three sections was in excellent condition and a predominate rating of seventy section for a rating of good condition. For the village access roads, forty nine sections were in excellent condition and sixty five in good condition while the rest were in fair to poor condition. Detailed Visual Inspection (DVI) was conducted on roadway sections identified by RCS to have major carriage–way maintenance or an RCS value greater or equal to three based on the RCS rating. Figure 6 gives a summary of the DVI of the surveyed sections.

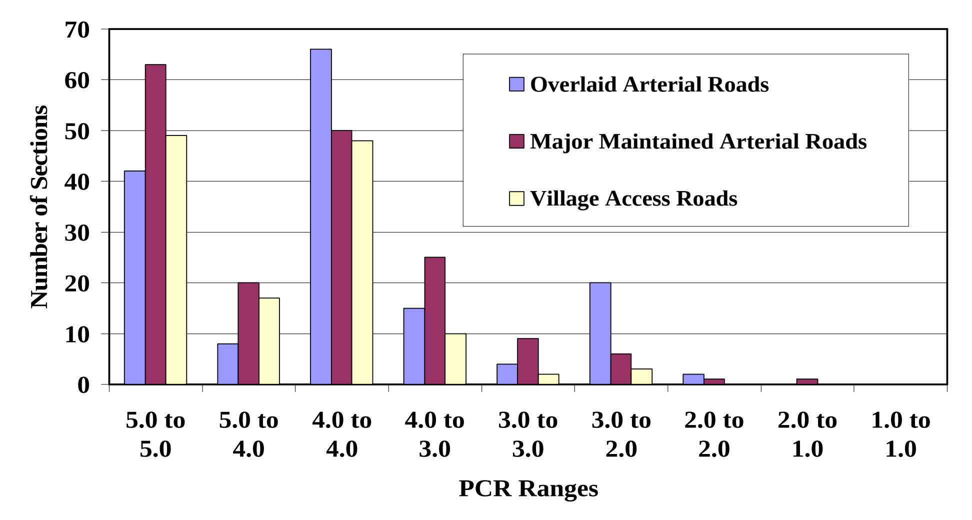


Figure 5: Pavement Condition Rating for Various Roadway Categories

Figure 6 represents the distribution of pavement life for all categories considered. The total number of sections for overlaid arterials, major maintained (reconstructed) arterials, and village access roadways are seventy-five, one-hundred and fifty-seven, and one-hundred and twenty-nine, respectively.

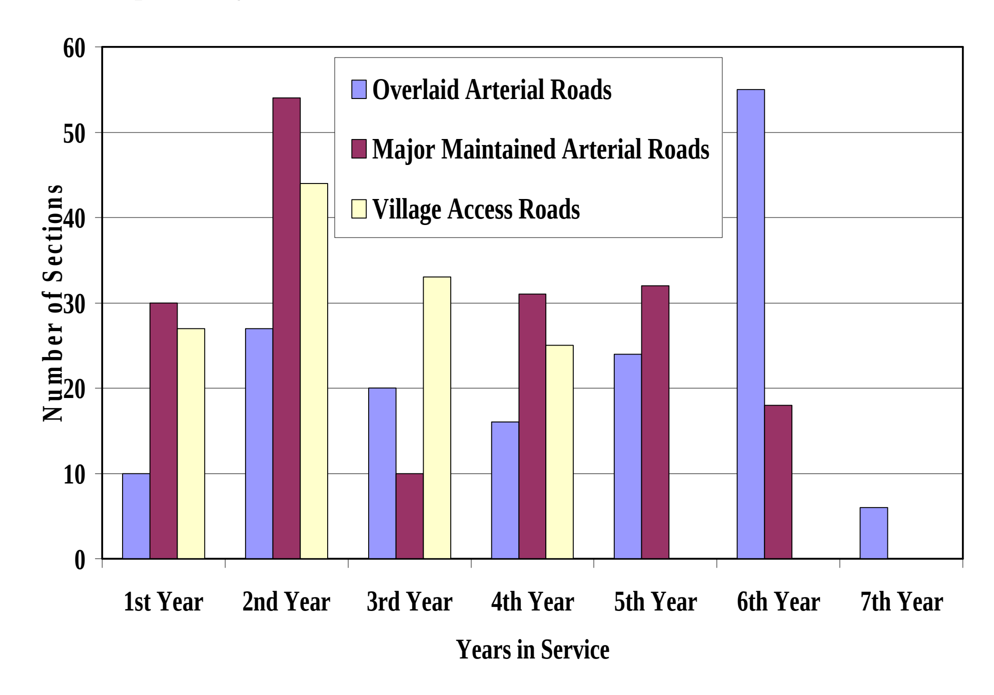


Figure (6): Distribution of Pavement Age for the Different Roadway Sections.

Data Analysis and Model Formation

The models in this research were developed based on statistical analysis correlating pavement performance as indicated by PCR index with pavement age and/ or design service life. For each treatment, representative in-service projects were selected and their corresponding needed data were used to develop pavement performance models.

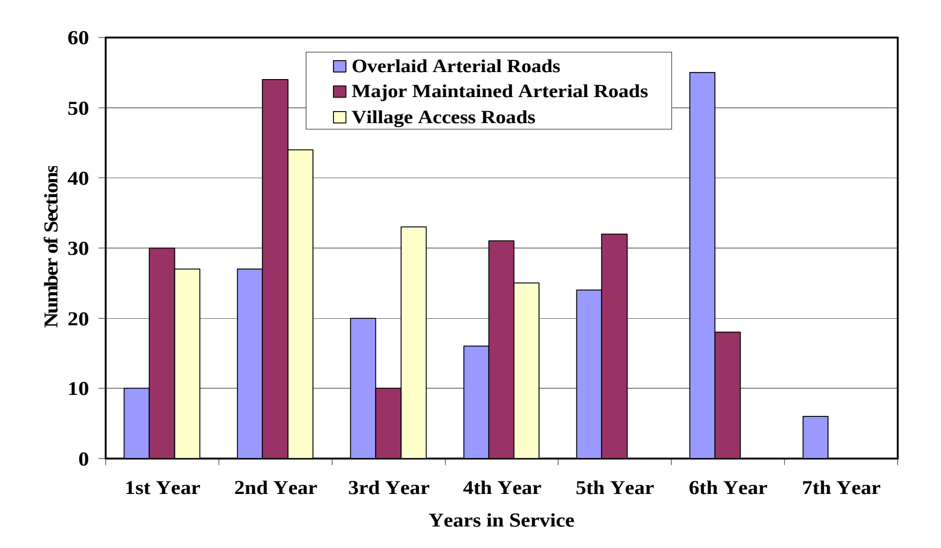


Figure (6): Distribution of Pavement Age for the Different Roadway Sections.

Analysis of Major-Maintained Arterial Roads

The methodology for developing pavement performance models consists of fitting the selected models to the observed pavement condition data and subsequently establishing equations for predicting the parameters of the model using regression analysis. It is important to choose a function that obeys the boundary conditions for the PCR value being predicted. In addition, the performance trend should initially start horizontally, bounded from above by a rating of five, then the pavement condition rating should decrease with time and asymptotes to a minimum value of zero. In this study, the polynomial model of the second degree for modeling pavement performance with pavement age was selected since it agrees with model conditions. Figure 7 illustrates polynomial regression model for major maintained arterial roads. A total of one-hundred and seventy-five surveyed sections were considered for model development. The curve developed in Figure 7 shows that the pavement reaches minimum acceptable performance level at PCR value of two at the age of nine years.

To apply the logistic growth model, the values had to be defined to meet the PCR data ranging from one to five, in which the distress-free pavement is considered to have a value of five.

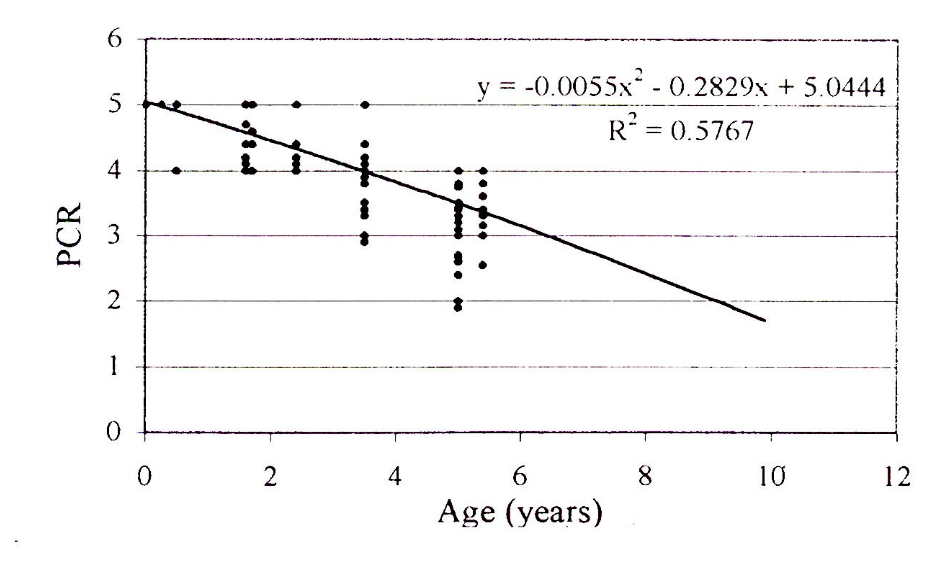


Figure (7): Performance Trend Using Polynomial Regression Model for Major Maintained Arterial Roads.

Figure 8 illustrates the logistic growth fitted to major-maintained arterial road sections. The logistic growth model reflects the nonlinear deterioration rate of the sections. The curve developed in this figure shows that the pavement reaches minimum acceptable performance level of two at age of 15.8 years for twenty years Design Service Life (DSL). The curve developed is used to predict the performance lives of arterial roads that have received major maintenance by applying polynomial regression equation of second degree. On the basis of the models ability to reflect a nonlinear determination rate and its previous use and acceptance for application to local road agencies. In addition, regression fitting is considered reasonably acceptable for such applications. It is believed that this is an appropriate deterministic model to apply for major maintained arterial roads.

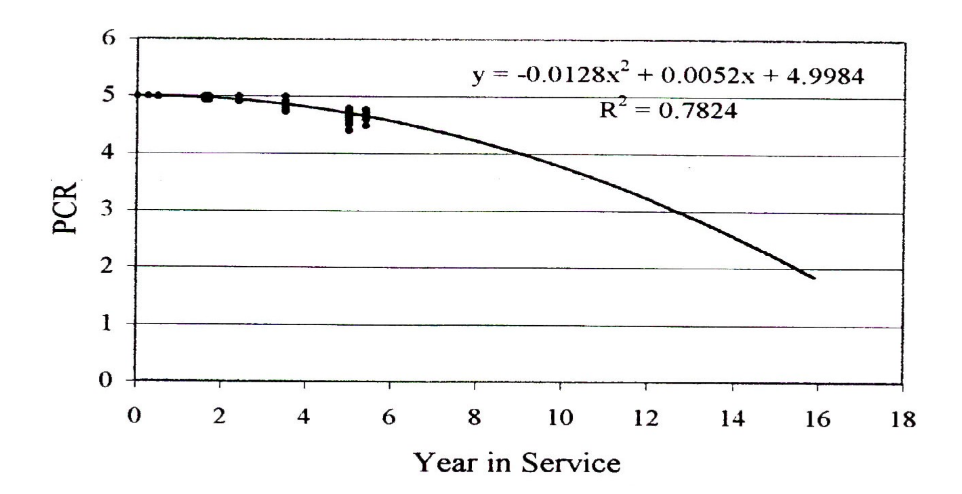


Figure (8): Performance Trend Using Logistic Growth Model for Major Maintained Arterial Roads.

The data applied in the Markov model for the major-maintained arterial roads sections surveyed in this research are shown in Table 2.

Table (2): Condition Data for Major Maintained Arterial Roads.

PCR	Number of Sections
5 to 5	63
5 to 4	20
4 to 4	50
4 to 3	25
3 to 3	9
3 to 2	6
2 to 2	1
2 to 1	1
1 to 1	0
Total	**175**

After the data was filtered, all the surveyed pavement segments were used in the development of the Transition Pavement Matrix (TPM). The formation of transition matrix and the transition probability matrix are shown in Table 3 a and b. The calculations required for the Markov model were conducted using MathCAD.

Table (3 a): Transition Matrix for Major-Maintained Arterial Roads.

Rating Value	5	4	3	2	1	Number of Sections
5	63	20	0	0	0	83
4	0	50	25	0	0	75
3	0	0	9	0	0	15
2	0	0	0	1	1	2
1	0	0	0	0	0	0
			Total Number of Sections			**175**

Table (3b): Transition Probability Matrix for Major-Maintained Arterial Roads.

Rating Value	5	4	3	2	1
5	0.759	0.241	0	0	0
4	0	0.600	0.400	0	0
3	0	0	0.600	0.400	0
2	0	0	0	0.500	0.500
1	0	0	0	0	0

Table 4 presents the Markov probability distribution for the first six years as calculated by MathCAD based on the transition probability matrix given in Table 3b. The probability distribution within each state vector is the main characteristic that makes the Markov model more attractive than the deterministic models.

Table (4): Probability Distribution Values from Markov Model for Major Maintained Arterials Roads.

Rating Value	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
5	**0.752**	**0.576**	**0.437**	0.3317	0.2581	0.1911
4	0.241	0.344	0.3683	**0.351**	**0.314**	**0.270**
3	0	0.0803	0.163	0.2204	0.249	0.254
2	0	0	0.0321	0.0813	0.1288	0.164
1	0	0	0	0.161	0.0407	0.0644

In Table 4, the state of maximum probability is shown in boldface. This path is the most likely deterioration path that the sections will follow. For example, at year four there is a probability of 0.3317 for the sections to stay at PCR value of five, but the highest probability value of 0.351 for that year is at PCR value of four. Figure 9 shows the plot of Markov model for major maintained arterial pavement sections. In Markov model, predicted future determination trend starts at the last rating the sections received. The line represents the average states of the pavement determined from a probability distribution based on the TPM established from the entire data set. It is clear that a constant rate of determination is nonexistent, and the variability inherent in pavement performance is addressed. This figure also shows that the prediction of performance trend of pavement sections indicates the pavement reaches minimum accepted performance level of two at age of ten years, which is unacceptable value for twenty years pavement DSL.

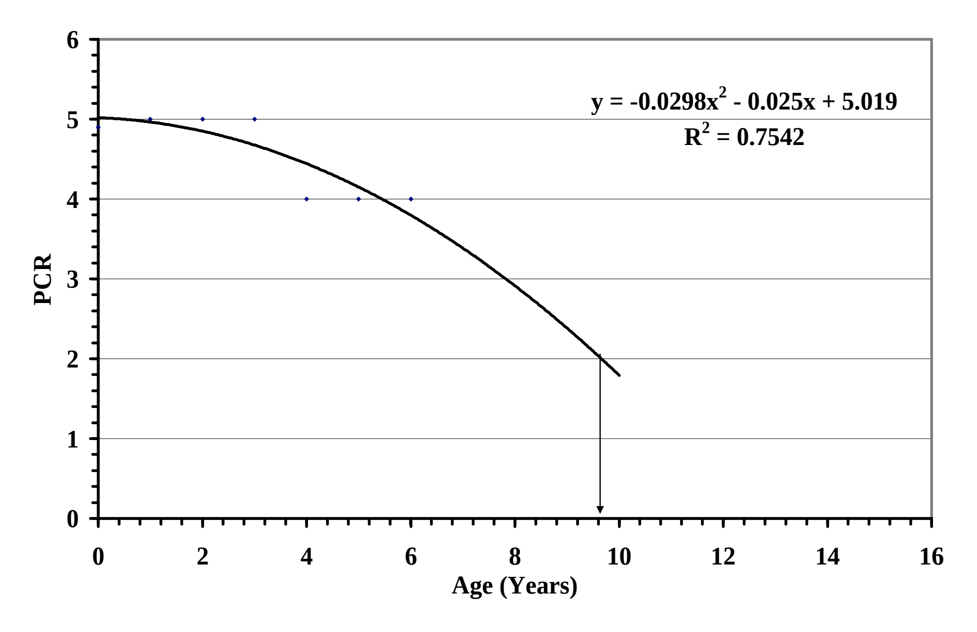


Figure (9): Performance Trend Using Markov Model for Major Maintained Arterial Roads.

Analysis of Overlaid Arterials Roads

Figure 10 illustrates the polynomial regression model of the second degree for overlaid arterial roads by which one hundred and fifty seven surveyed sections were considered for model development. The curve developed shows that the pavement reaches PCR value of two at age of eight years. Figure 11 illustrates the logistic growth model fitted to overlaid arterial roads sections. The curve shows that the pavement reaches minimum accepted performance level of two at age of nine years for ten years DSL. The curve developed is used to predict the performance lives of overlaid arterial roads by applying polynomial regression equation of a second degree. On the basis of the model's ability to reflect a nonlinear deterioration rate and its previous use and acceptance for application to local road agencies, it is believed that this is an appropriate deterministic model to apply for overlaid arterial roads.

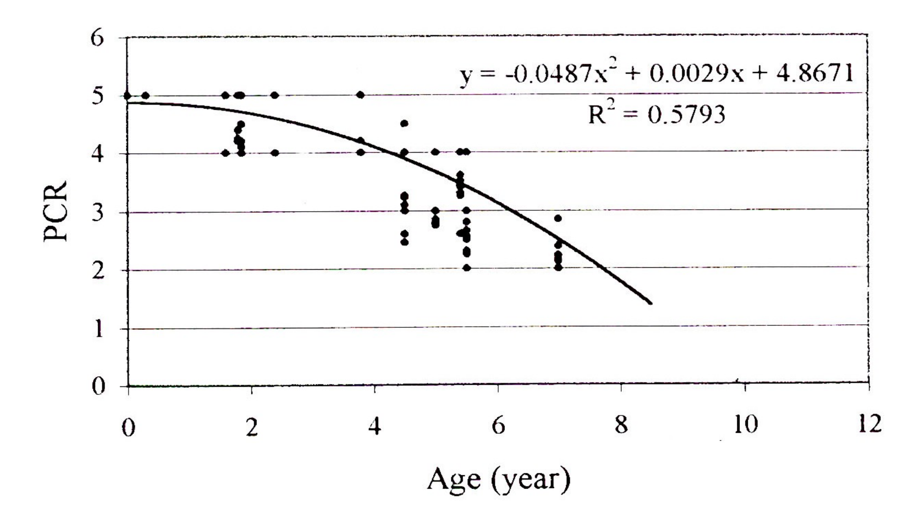


Figure (10): Performance Trend Using Polynomial Regression Model for Overlaid Arterial Roads.

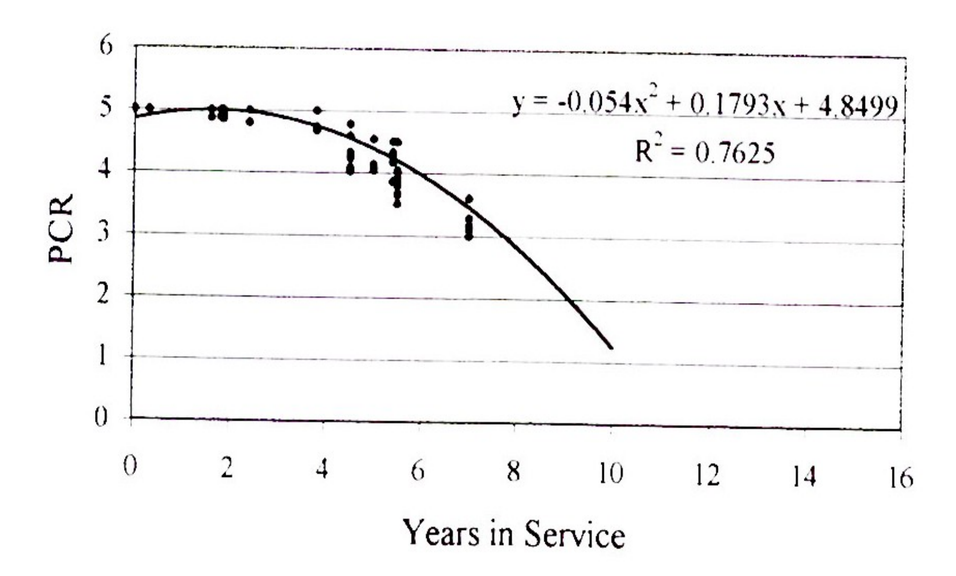


Figure (11): Performance Trend Using Logistic Growth Model for Overlaid Arterial Roads.

After data filtering, surveyed pavement segments were used in the development of the TPM, formation of transition matrix and the transition probability matrix. Figure 12 illustrates the Markov model for overlaid arterial pavement sections. In Markov model, predicted future deterioration trends starts at the last rating the sections received. The line represents the average state of the pavement determined from a probability distribution based on the TPM established from the entire data set.

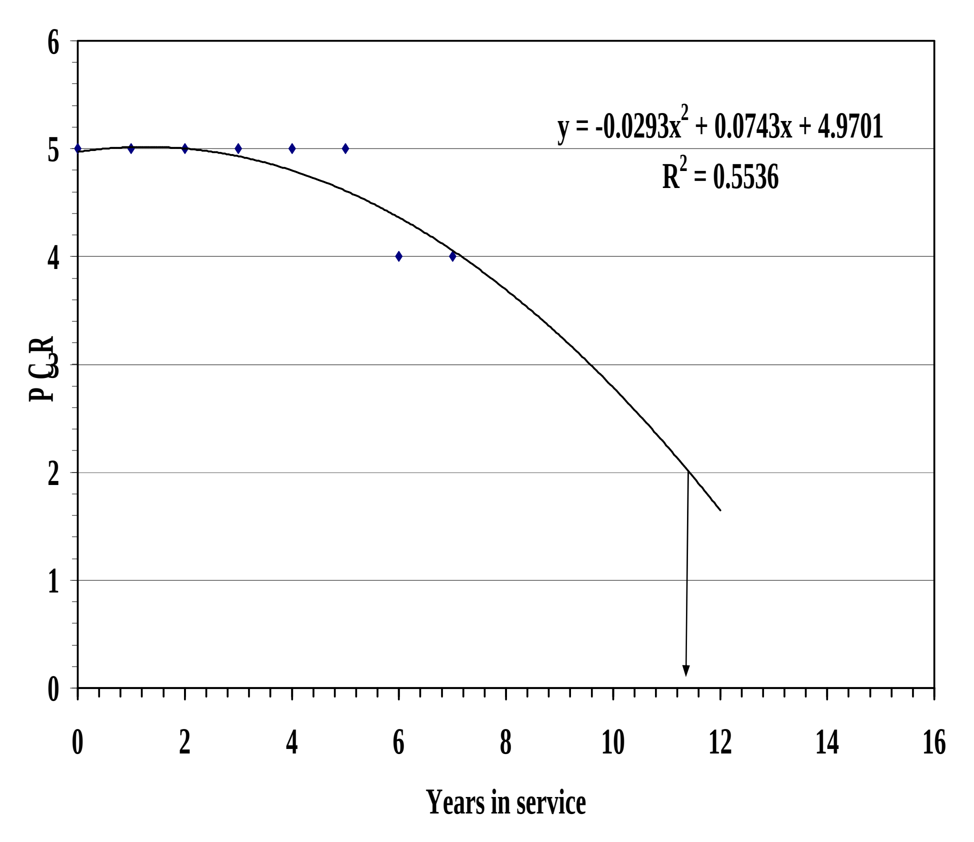


Figure 12: Markov Model for Overlay Arterial Roads

The prediction of performance trend of pavement sections shows that the pavement reaches minimum accepted performance level of two at age ten years, which is around pavement design service life of ten years.

Analysis of Village Access Roads

A total of one hundred and twenty nine surveyed sections were considered for model development for village access roads. Figure 13 illustrates a polynomial regression model developed for village access roads. The performance trend doesn't take a horizontal initiation. As pavement ages with time, the pavement condition rating decreases and asymptotes to minimum value of zero. The slope of the curve at starting years of pavement life is large compared to its slope at older age. This case contradicts the concept of pavement performance behavior. Thus, this model was not used in model evaluation.

Figure 14 illustrates the logistic growth model for village access road sections. The curve shows that the pavement reaches minimum acceptable performance level of two at the age of 10.5 years for ten years DSL. The curve matches the boundary conditions and agrees with natural pavement performance behavior than that of the polynomial model obtained by fitting the surveyed raw data directly.

Figure 15 illustrates the Markov model for village access roads. The curve reaches minimum accepted performance value of two at age of 7 years.

The results of pavement life estimates for the selected pavement sections of major maintained arterial, resurfaced arterials, and rehabilitated village access roads are illustrated in Figure 16. In general, the reconstructed arterial has longer performance life than the arterial resurfacing and village access roads. Nevertheless, it should be emphasized that the traffic patterns and volumes may be totally different for each.

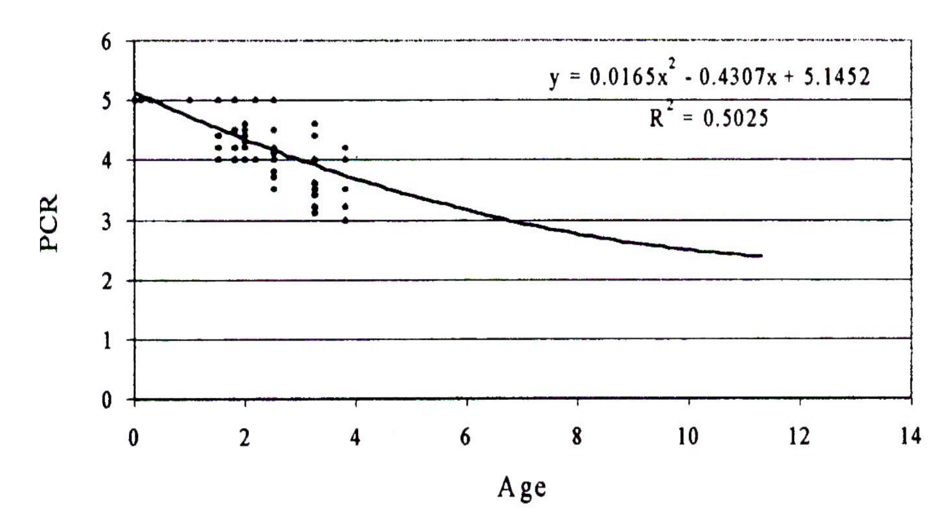


Figure (13): Performance Trend Using Polynomial Regression Model for Village Access Roads.

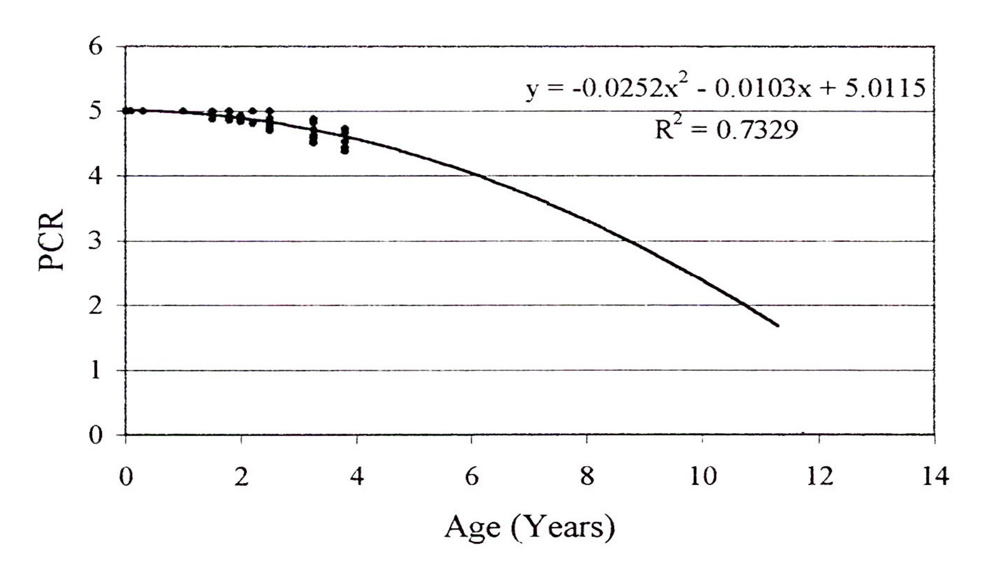


Figure (14): Performance Trend Using Logistic Growth Model for Village Access Roads.

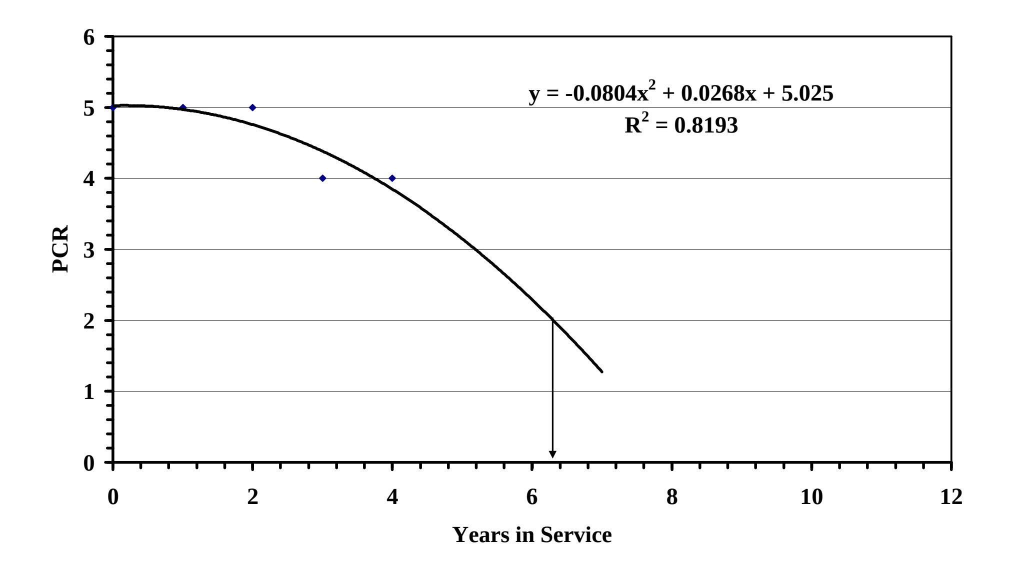


Figure (15): Performance Trend Using Markov Model for Village Access Roads.

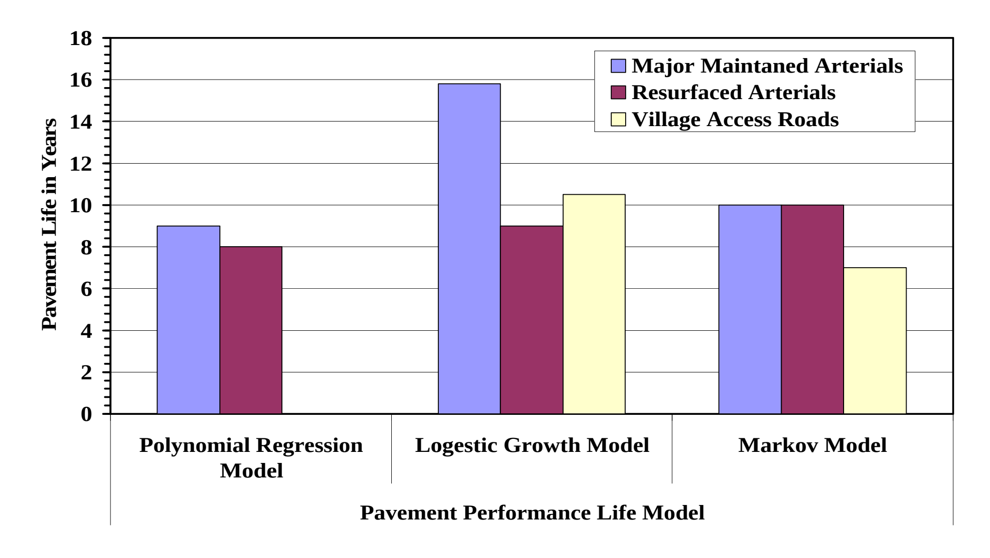


Figure (16): Pavement Life Estimates for the Different Types of Pavement Surface and Roads.

Conclusions

Comparing the results of the aforementioned models, the logistic growth deterministic model was a better fit for calibrated PCR data compared to their regression fitting values while the Markov model was only suited for the overlaid arterials. The curves developed using logistic growth model for the major maintained arterial, overlaid arterial, and rehabilitated village access road sections were in agreement with the natural behavior of pavement performance and more realistic than the results of Markov model with the exception of the overlaid arterials.

In Markov model, the pavement of major maintained arterial road reached the minimum acceptable performance level at age of ten years. This means that the pavement must have a major maintenance action at earlier age than it is expected or designed for. While the developed logistic growth curve showed that the pavement must have a major rehabilitation action at 15.8 years, which is closer to the designer expectation of twenty years, even though the R^2 value for both models was 0.78.

The model developed by applying both the logistic growth equation and Markov probabilistic model for the overlaid arterial road sections gave comparable results resembling the true deterioration behavior. In Markov model, the pavement reached the minimum acceptable performance level at age of eleven and half years. This means that the pavement must have a major rehabilitation action around the age that is expected or designed for. Furthermore, the developed logistic growth curves showed that the pavement must have a major rehabilitation action at age of nine years. Therefore, both models meet the designer expectation for design service life of ten years, with a slight edge in favor of the logistic growth model considering that the local construction practices rarely have a service life more than the design life, and the R^2 for the logistic growth model was slightly more than that of the Markov model.

The model developed by applying logistic growth equation for the rehabilitated village access road sections compared to Markov

probabilistic model was more realistic; since in Markov model, the pavement reaches the minimum acceptable performance level at age of 6.5 years. This means that the pavement must have a major rehabilitation action at earlier age than it is expected or designed for. While the developed logistic growth curve showed that the pavement must have a major rehabilitation action at age of 10.5 years, which is closer to the designer expectation, also the R^2 value for logistic growth model is larger than that of Markov model.

From the comparison of results, it is concluded that the logistic growth model is a more suitable model to apply for the road types being studied at the local level in Palestine while the Markov model is only suited for the overlaid arterials. For a better understanding and eventually better refinement of the models developed, it is important to adopt a road monitoring system in Palestine.

In summary, based on applying multiple forms of deterministic and probabilistic performance models to local roadway network in Palestine, the following conclusions can be reached:

1. The logistic growth model is a suitable model to apply for Palestinian local roadway network.
2. The Markov model is only suitable for the overlaid arterials.
3. Urban arterials having major maintenance (reconstruction) have longer performance life than the urban arterial having resurfacing (overlaid).
4. Village access roads having major maintenance have longer performance life than the village access roads having resurfacing.
5. For a better understanding and eventually better refinement of the models developed, it is important to adopt a road monitoring system in Palestine.

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